10th International Command and Control Research and Technology Symposium
The Future of C2

Command and Control in Complex and Urban Terrain: Human Performance Modeling Decision Making and Cognitive Analysis

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Problem

Current Command and Control (C2) systems don't provide commanders/leaders/soldiers with the information collection capabilities and decision aids needed to collectively plan the battle; to see first, understand first, act first, and finish decisively during close combat in complex and urban terrain. Specific barriers to decision superiority include the following: inadequate collaborative decision aids to visualize, describe, and control mixed assets (sensors, robots, and Soldiers); algorithms for decision-making with partial or incomplete information, inadequate algorithms for tailored, dynamic information push/pull to support the integration of mixed assets in close combat, and inadequate algorithms for situational awareness and focus in complex/urban terrain.

Relevance to Command and Control

The complexity associated with urban terrain arises not only from physical characteristics of the landscape (e.g. residential and commercial districts, constraints on maneuvers) but also from the socio-economic features. Detailed knowledge of the urban infrastructure (physical, cultural, social, economic, political) is critical to the military units who must maneuver through the environment (Joint Staff, 2000, 2003). It is the interactive nature of three urban characteristics: man-made structures, a sizeable and dense population, and supporting infrastructure that creates dynamic uncertainty for military commanders (Military Technology, 2003). This uncertainty is compounded by changes in the modern battlefield to include coalition and interagency coordination, shifts between combat and peace support operations (often in very short time periods), and the increasing use of technology to support situation awareness. Effective command and control is certainly challenged by these characteristics, not unique to the urban environment, but magnified in terms of their impact to tactical C2 operations.

Approach

To investigate these complex set of interactions, we formed an interdisciplinary research team capable of addressing these unique problem issues from multiple perspectives. This team

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included subject matter experts in information management and fusion, teaming, C2, robotic control, collaboration, human factors, training and doctrine, and decision making. A significant contribution to the overall research objective is the cognitive analysis of decision making in complex and urban terrain. This emerging battlefield environment is strategically and tactically novel because of the nature of the asymmetric threats posed by our adversaries and by the need for new supporting technologies. The uncertainty that is presented by these conditions increases decision makers' stress levels and suggests the need for advanced decision support tools that are capable of augmenting human performance in time constrained and culturally complex domains. This paper addresses one critical component of C2 in complex and urban terrain; the use of human performance modeling to explore an effects based approach to coalition planning and execution.

Models are an efficient tool for evaluating alternative organizational structures, personnel configurations, and communication networks in a C2 domain. We used a modeling architecture known as C3TRACE (C3 Techniques for Reliable Assessment of Concept Execution) to evaluate a multinational concept of effects based planning for an urban scenario. The architecture required us to define an organizational structure, identify tasks, task completion times, work assignments, and the flow of communications through the C2 system. Communications were defined by the type of information contained in the message, action required for message completion, and contributions of the information to three levels of situation awareness (Endsley, 1995). As we executed the model, communications were degraded by use of an embedded algorithm based on time delays and the original volatility of the message. Messages that contain information on 'enemy where', for instance, degrade faster over time than those that identify 'enemy who', since the latter is less likely to change than the former.

The U.S. Joint Forces Command (USJFCOM) Multinational Experiment 3 (MNE3) was used to develop and test a new command structure and planning process in a coalition operational headquarters (USJFCOM, 2004) using this C3TRACE modeling architecture. In addition to the model execution, data was collected during the experiment and used to extend our understanding of the C2 challenges in this environment.

Method

Modeling the Planning Process

To build the C3TRACE task flows and assignments, we used the prototype Effects Based Planning (EBP) concept of operations that was developed for use in USJFCOM MNE3. The MNE3 EBP strategy drew upon the emerging concepts of Network Centric Warfare and Effects Based Operations (Smith, 2002). Smith defines EBO as "coordinated sets of action directed at shaping the behavior of friends, foes, and neutrals in peace, crisis, and war" (p. xiv). This new way of thinking about military operations is characterized by the use of kinetic and non-kinetic actions to shape adversary behavior and the inclusion of non-military experts in the decision process to determine the best method selecting and implementing effects. The prototype EBP concept of operations included five major steps: Mission Analysis, Effects Assessment, Action Risk Assessment, Wargaming/Course of Action (COA) Assessment, and Effects Synchronization. These steps were designed to be parallel, not linear, processes. Planners were

required to select effects (from an intelligence data base) that met strategic objectives, and to pair these effects with acceptable actions. Once these selections were made and approved by the commander, they were prioritized, war-gamed, and synchronized in time, space, and by resource. We modeled the EBP process by extracting the task flows, assignments, and dependencies between tasks from the operational concept. To estimate task times, we asked subject matter experts from the MNE3 group to provide estimated times for task completion.

Modeling the Organizational Structure

The organizational structure used for the MNE3 EBP experiment was based upon the USJFCOM Standing Joint Force Headquarters (SJFHQ) model. In this prototype, the staff is divided into five cells: Command, Information Superiority (IS), Plans, Operations, and Knowledge Management (KM). For purposes of the experiment, a Coalition Interagency Coordinating Group (CIACG) cell was added. The SJFHQ is a 55 person cross-functional team of operational planners and information C2 specialists who serve as a core team for a coalition task force when needed. The IS cell is charged with intelligence collection and analysis. The KM cell is required to maintain the information technology equipment and to manage the flow of information and the maintenance of knowledge activities and products (e.g. procedures, documents, and guidance). The CIACG was charged with providing information and advice to all cells as needed. To model the organization, we used the EBP concept of operations to identify the positions required in each cell and listed them in the model. We extracted personnel shaping factors (e.g. rank, experience, military occupational specialty (MOS) codes) from the EBP concept of operations.

Experiment Design

The MNE3 experiment was designed to simulate a distributed Coalition Task Force (CTF) that was required to follow the NATO Response Force (NRF) into a nation for the purpose of conducting stability and support operations. Six nations participated in the CTF organization: Australia, Canada, France, Germany, the U.K., and the U.S. A command element of NATO comprised the simulated NRF headquarters. CTF members were distributed between sites in each nation and the NRF was co-located at one site in Germany. Participants, to include the NRF headquarters, used a commercial collaborative tool to complete the planning process.

Participants

There were 117 participants in the CTF site and 34 in the NRF site[1]. In the former, national players were represented in the following numbers: Australia (7, 6%), Canada (14, 12%), France (15, 13%), Germany (18, 15%), U.K. (21, 18%) and U.S. (42, 36%). The service affiliation of all participants was as follows: Army (27%), Air Force (16%), Navy (18%), Marines (1%), Civilian (11%), defense contractor (24%), and other (3%). The other category included non-military individuals supporting the inter-agency planning function. The level of education among participants included 24% with a Bachelor's degree, 49% with a Master's degree, and 7% with a PhD. Respondents who did not report a formal college degree reported successful completion of professional military education (20%). Fully 90% of participants reported prior

[1] Though the CTF was based on a 55-person SJFHQ, the number of participants in the experiment was larger due to the need to accommodate all nations and to have representatives to each supporting cell in the national laboratories.

military experience. Of this group, 80% had over 16 years of experience in the military. Despite this high level of expertise, however, multinational military experience was far less common. Twelve percent indicated no such experience, followed by 23% with less than one year, 32% with 1-3 years, 22% with 4-6 years, and 11% with 7-10 years. Of the participant sample, 77% reported no prior experience with EBP and 70% had no experience working in a distributed collaborative environment.

Survey Questions

In the follow-on experiment, MNE3 EBP, we used the model-test-model method to evaluate the EBP concept. We developed a model based on the concept of operations prior to the experiment, and used survey questions and observations during the experiment to validate the process and organization. Survey questions were developed for each of the four process phases (Effects Assessment, Actions Assessment, Wargaming/COA, and Effects Assessment). Though the first stage of Mission Analysis was included in the model, it was deleted from the experiment to save time. These questions asked participants to comment on the organizational structure for that process phase, the participants used in that phase, and if tasks were missing or redundant. Each question was answered on a 7 point scale (1 = low, 7 = high).

We also asked participants to rate their situational understanding and judgments of information flow during each of the four planning stages. These questions covered 8 areas concerning participants' ability to use information to generate their situational awareness. Questions asked participants to rate their own ability to keep up to speed with information, to understand the situation, to sense the future, to know how to act, to keep up with the information flow, to make sense of the situation, to predict the future, to meet objectives, and to rate the organizational structure impact on information flow. Again, these questions were answered on a 7 point scale (1 = low, 7 = high).

In addition to the survey questions identified above, we included questions that asked respondents to provide comments on the process and organization elements of EBP. These are reported after the quantitative data.

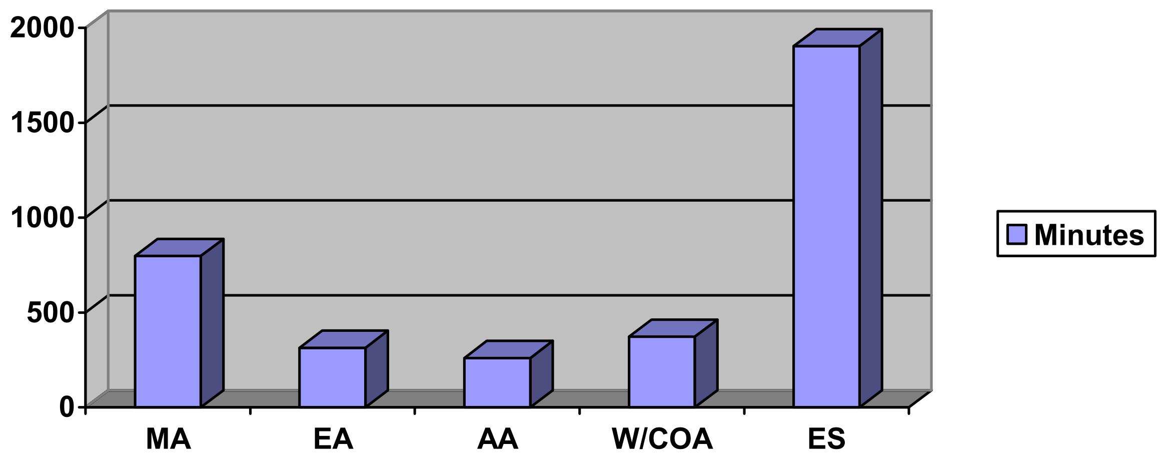
<u>Results</u>

Model results: Task Times

The initial model results, based solely on the EBP tasks and organization contained in the concept of operations, suggested that the mission analysis and effects synchronization phases of EBP (the first and last stages) required more time than effects assessment, actions assessment, and wargaming/COA development. Time was measured in minutes. The minutes required for each phase in the model run were: Mission Analysis (797), Effects Assessment (314), Actions Assessment (260), Wargaming/COA (372), and Effects Synchronization (1903). The chart in Figure 1 shows these data, suggesting that the Effects Synchronization phase took over twice as long as the next longest phase, mission assessment, and nearly four times as long as the effects assessment, actions assessment, and wargaming stages. This is a function of the tasks contained

in each phase, the collaboration required among tasks, and the time required for the requisite completion of each task.

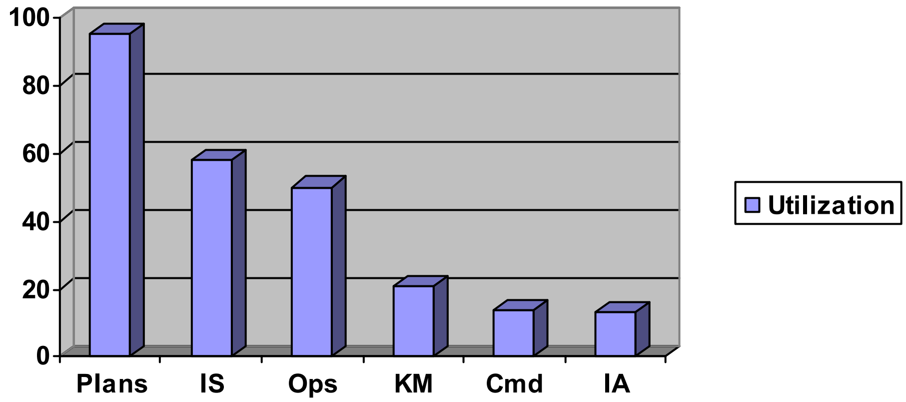
Figure 1. Model results of task times by EBP Phase.



Model results: Staff Utilization

The C3TRACE model results, based on the assignment of tasks to personnel, indicated that the groups were not equally engaged in the process. The Plans group had a utilization rate of 95%, followed by the Information Superiority (58%), Operations (50%), Knowledge Management (21%), Command (14%), and Interagency Coordination (13%). These findings are displayed in figure 2, and suggest that the simulated headquarters staff was not adequately involved in the EBP phases. It is not surprising that the Plans, Operations, and Information Superiority cells were highly utilized, given the nature of the planning process (Information Superiority provided intelligence analysis). If this were a typical staff planning process, the low utilization rate of the commander would not be unusual. However, this process was designed to have the commander become more involved (by virtue of the knowledge management processes in use) to avoid lengthy delays due to staff misunderstanding of commander's guidance reports. The low utilization rates for the Interagency group are understandable due to their influence during specific and constrained periods. Due to the distributed nature of the CTF and the complexity of the experiment, it was not possible during each phase of the experiment to keep detailed track of the percentages of time each group was utilized in the EBP process, therefore an R2 calculation of interdependency was not possible.

Figure 2. Utilization by EBP Organizational Cell



Survey Results: EBP Process

After each EBP phase, respondents were asked to rate and provide comments on their ability to complete that phase based on the product provided from the previous phase, the staff included in the phase, and identified tasks for that phase. Table 1 shows the descriptive results. Again, the responses were based on a 1-7 scale (1=low, 7=high). For the first three phases, participants generally agreed that they had the necessary product to continue the EBP process. However, in the Effects Synchronization stage, this rating dropped to a mean of 3.44 (SD 1.36), indicating that the Wargaming/COA phase did not produce the requisite product for planning to proceed in an efficient fashion. To answer the question of whether or not the phases had the right mix of staff, respondents almost unanimously answered in the middle of the scale for each phase, a neutral or noncommittal finding. For the questions of the redundant or missing tasks, respondents again gave an almost neutral response, with the mean scores hovering around the median (3.5) or slightly above (4.0).

Table 1. Organizational Responses of EBP

Question	Effects Assessment			Actions Assessment			Wargaming/COA			Effects Synchronization		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
The product from the previous stage was sufficient to proceed with current phase.	152	4.35	1.29	150	4.37	1.14	146	4.05	1.23	142	3.44	1.36
The organization for this phase had the right	152	3.86	1.46	150	3.86	1.27	146	3.99	1.20	142	3.84	1.23

participants.												
Were tasks in this phase redundant?	152	3.93	1.17	150	4.08	.99	146	4.06	.97	142	4.08	.91
Were tasks in this phase needed?	152	4.02	1.22	150	4.03	.97	146	4.15	1.09	142	4.07	1.00

Qualitative comments were sought from participants on how the organizational design of the MNE3 EBP might have influenced their ability to perform the planning tasks. Table 2 captures the major response categories related to the question: "How did organizational problems impact communication flow?" 136 participants answered these questions, offering a total of 106 comments. A content analysis was performed of the responses to the survey question (not every respondent chose to provide comments). Respondents generally commented that the organization used in MNE3 to explore EBP was too complicated. They generally felt that there were an excessive number of teams organized to perform tasks, and some players were allocated to more than one task at a time. Role confusion was common among participants, resulting in a lack of efficiency. This not only impacted knowledge of one's own role or task, but that of others in the distributed environment as well. This made it extremely difficult for teams to operate and form a shared understanding of their task at hand.

Table 2. Comments about the EBP organization

Organizational problems impacting communication flow	Responses
Confusion within teams about tasks	18
Confusion among teams about tasks	22
Lack of knowledge of other teams' functions	24
Too many meetings to be productive	32
Lack of understanding of my role	18
Lack of understanding of other roles	25
Too many boards, centers, and cells resulted in a loss of focus for planning process	35
Too many people in a group to be productive	25
Requirements for attendance in informal groups was unclear and ill-defined, resulting in people missing meetings or being in the wrong group	20

Survey Results: Situation Understanding and Information Flow

We ran a multivariate analysis of variance between participating nations in their response to questions asking for their rating of situation awareness and information flow in each of the EBP process steps. No significant differences among the nations were noted in the first three stages of Effects Assessment, Actions Assessment, and Wargaming/COA. In the final stage, Effects Synchronization, a main effect difference was found $\underline{F}$ (48, 328.81) = 1.762, $\underline{p}$ = .002. The univariate test showed a significant difference in the ability to 'have a good sense of the future, decide how things would develop' $\underline{F}$ (6, 73) = 2.967, $\underline{p}$ = 012. For this question, mean results with standard deviations were as follows: Australia (2.5, .71), Canada (2.2, 1.1), France (1.8, .84), Germany (2.75, 1.1), U.K. (1.83, .94), U.S. (2.37, 1.01), and NATO (2.16, .94). Thus, among the coalition, France and the U.K. had lower scores than their colleagues, indicating that

these nations reported a significantly lower ability to predict how events would develop in the EBP process.

These results are similar to the model results presented earlier that show the Effects Synchronization stage taking almost four times as long as the other stages. The ES process, because it must integrate all chosen effects and actions in time and space, among elements of national power (e.g., not just the military resources), is a very demanding and time-consuming process. The survey results appear to validate the model results that this stage of the process needs considerable attention to reduce the cognitive workload of C2 staff.

Observation Results: Model, Process, and Organization Redesign

The observations we made during the MNE3 experiment paralleled the model and survey results, in that EBP tasks had been inadequately parsed among the planning phases, the organizational structure was not sufficiently suited to the parallel process that was desired, and the process as designed was too complicated for a distributed headquarters to use with existing collaborative and data management technology. We observed many requests for help in locating documents, finding collaborative meeting rooms, and determining in which meeting one should participate. Our analysis suggests that the distributed team structure functioned poorly and was mainly used to communicate results achieved at each stage of the process, rather than for collaborative decision making. Because these distributed team structures were unfamiliar and cumbersome, players reverted to more familiar operating structures, often with co-located participants.

Discussion

The proposition upon which the MNE3 EBP was built was that the application of this new process would improve an operational commander's ability to broaden the range of effects and actions considered, respond in a more agile fashion to changing conditions, coordinate actions with multinational military and nonmilitary participants, and better enable the exploitation of military and nonmilitary knowledge. The EBP process generated to meet these objectives was lengthy and linear, though concept developers attempted to create a parallel process. The organization applied to the planning process was a cross-functional design intended to flatten the hierarchy and speed the information sharing and decision making process.

The initial C3TRACE model results indicated that the process phases were very unequal in their duration and that the staff was underutilized with the exception of the planners. This perhaps points out a tendency to assign planning tasks to planners, instead of adopting the preferred cross-functional design. This tendency, if followed, will negate the benefits that are provided by the more open and inclusive EBO process that is designed to involve the non-military elements of national and coalition power. The fact that the Effects Synchronization stage was uniquely different than the previous stages both in the model and in the experiment suggests that the complexity of this stage must be addressed. Possible options for concept developers includes organizational solutions (re-distributing the number and types of personnel assigned to these tasks), procedural (streamlining tasks where possible), and technical (developing tools that can

reduce the cognitive workload for staff). The benefit of modeling prior to experimentation can not be overstated as this provides the opportunity to 'dry-run' concepts in a simulated environment.

The survey responses and the observations from the experiment validate the initial model results. The qualitative participant comments clearly convey the confusion that existed in the experiment regarding the organizational structure of EBP as used in MNE3. This confusion was noted in observer notes. The data that suggest that participants were neutral in their opinions of whether or not tasks were redundant or missing suggests that they were unsure, possibly as a result of their general confusion with the overall process.

The distributed teams participating in this experiment included a range of experience levels with regard to the MNE3 EBP process. Many participants had been engaged in pre-experiment planning conferences while others were pulled by their respective nations from other requirements to meet staffing requirements. More within-cell team experience would undoubtedly have contributed to a higher level of expertise and less confusion about the process and organization. For example, those participants who had experience with MNE3 through previous meetings were generally relied upon as cell leaders. However, we must question whether this higher level of team cohesion can be realistically expected. Indeed, one reason for distributed organizational models is to allow for ad-hoc and dynamic team formation. The collaboration environment should ideally become sufficient to allow for rapid team cohesion in the absence of prior face to face meetings.

Perhaps because the experiment was so intensely focused on completing a process with which most participants were unfamiliar, in a distributed environment and with unfamiliar data processing technology, participants were less focused on relationship building than they were on task accomplishment. The experiment day generally required 10 hours of on-line time, with an additional 2 hours for meetings or general support efforts. However, by the end of the experiment (which lasted three weeks), there was a decided increase in camaraderie within and across cells. This suggests that even in the face of intense, albeit simulated, pressure; the need for team cohesion is an important and motivating factor.

Conclusion

The use of a model-test-model methodology in support of a large experiment was beneficial to the evaluation of the experiment objectives. Prior to the experiment start, we suspected that the TTPs gave an inaccurate description of the assignment of tasks needed for full EBP execution. [2] Survey and observational results from the experiment validated these model implications. The nature of a cross-functional headquarters is clearly not well understood and needs further refinement and clarification through TTPs.

[2] Unfortunately, due to the prolonged planning period needed for an experiment of this size, we were unable to influence the experimental support documents to make them more cross-functional.

In future Effects Based Operations experiments, the use of the C3TRACE modeling architecture will be used to evaluate the state of TTPs prior to experiment start. Because we are starting the modeling process much earlier, we will be able to influence TTP changes in a proactive way.

Effects based planning, as experimented with in MNE3, was a concept in need of further refinement. This was especially noted in the organization problems, which impacted the ability of the staff to complete the process steps. These inadequacies were noted by experiment staff and appropriate steps taken to reduce these risks in future experiments. Most important, the decision to enact the final experiment (MNE4-Effects Based Operations in an Operational Coalition Headquarters) with a two-year delay was made. This allowed participating nations to conduct limited objective experiments to explore enabling and operational concepts in more detail. These workshops and experiments allow a fuller exploration of the many elements of Effects Based Operations (of which EBP is a part) to avoid the problems noted in this paper.

In summary, the concept of Effects Based Planning and Operations provides a promising solution to the problem of complexity in the urban terrain environment. The increasing focus on non-kinetic effects is recognition that modern urban warfare cannot be effective by the destruction of political, economic, social, and cultural infrastructure systems. This new urban initiative requires the experience and expertise from interagency representatives who can advise military commanders on alternative methods to achieve strategic objectives. This new form of knowledge is made possible in today's command and control centers with the advent of networked information and technology systems of systems. However, unanswered questions remain to be answered for the full realization of effects based systems. First among these is determining the best organizational structure capable of implementing coalition operations in a rapid fashion. Second, applied technology is required to manage the complicated data requirements and to enable the use of distributed collaborative systems to minimize the C2 footprint. These are questions well suited to the use of modeling tools as described in this paper. The modeling effort will continue to support the maturation of the EBP concept and should help to reduce the uncertainty that currently complicates operations in complex urban terrain.

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C2 in Complex Urban Terrain: Human Performance Modeling

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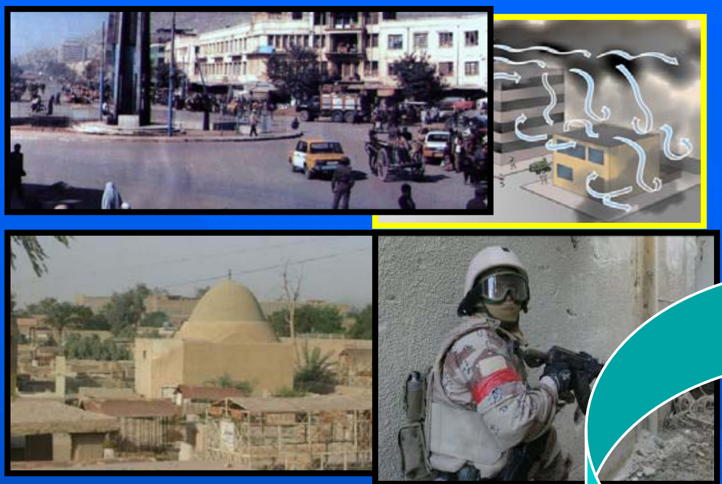
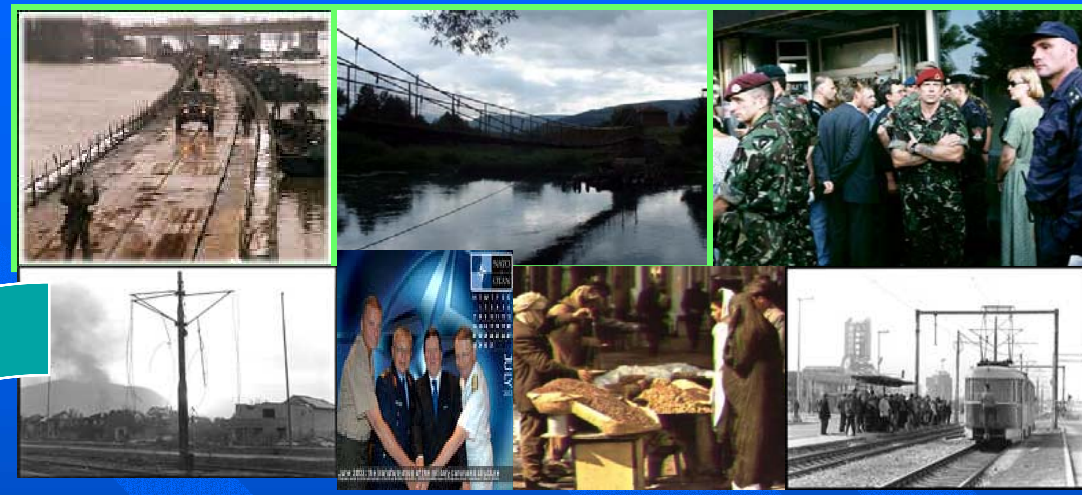
Outline

- Characteristics of complex urban terrain
- New approaches to decision making in uncertain environments
- C3TRACE application and results
- Future research

Decision Uncertainty in Complex and Urban Terrain



Physical terrain



Infrastructure systems: political, economic, social, transportation, utilities

Interactions Create Complexity and Uncertainty

Population density and cultural characteristics

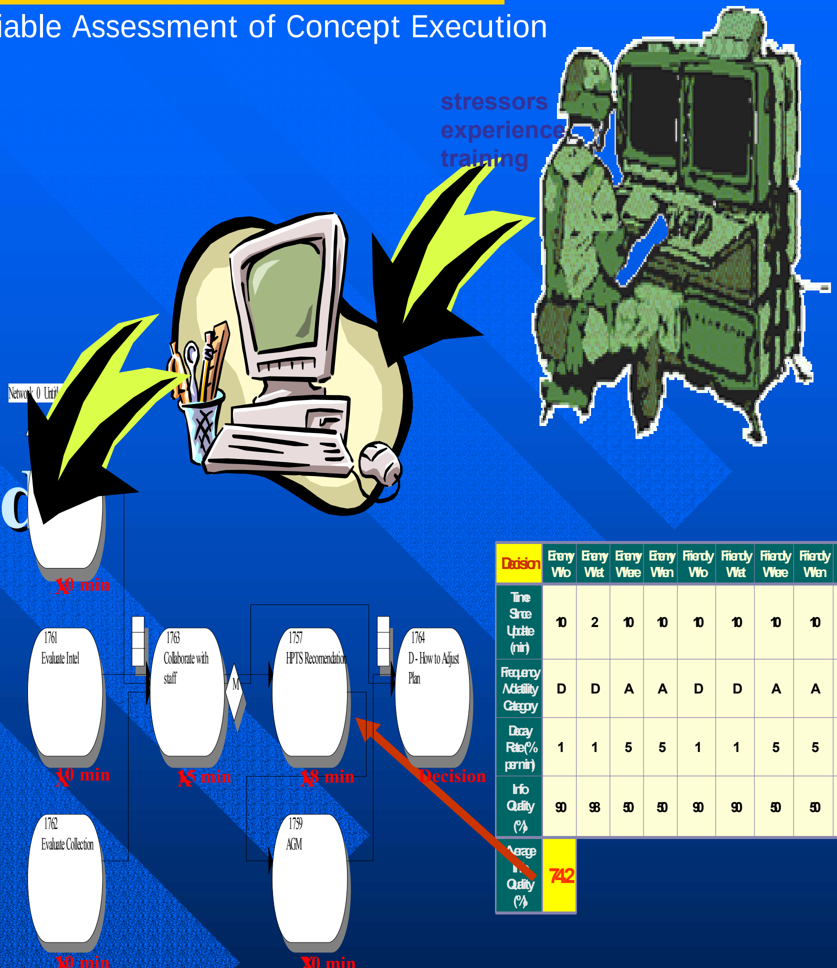
"We cannot simply maneuver through the terrain. We must also "maneuver" through the population, e.g. physically maneuvering along cultural avenues of approach vice physical, or maneuvering through the systems that support the population." USJFCOM Concept for Joint Urban Operations , 1/14/2004.

New Approaches to Decision Making

- Net centricity enables distributed collaboration with a ‘reach back’ capability to rear supporting organizations
- Distribution and collaborative networks allow non-military representatives of national power to contribute to decisions
- Effects based planning directs the coordinated (DIME) efforts of a coalition toward shaping others’ behavior

C3TRACE Architecture

Command, Control, & Communications: Technically Reliable Assessment of Concept Execution

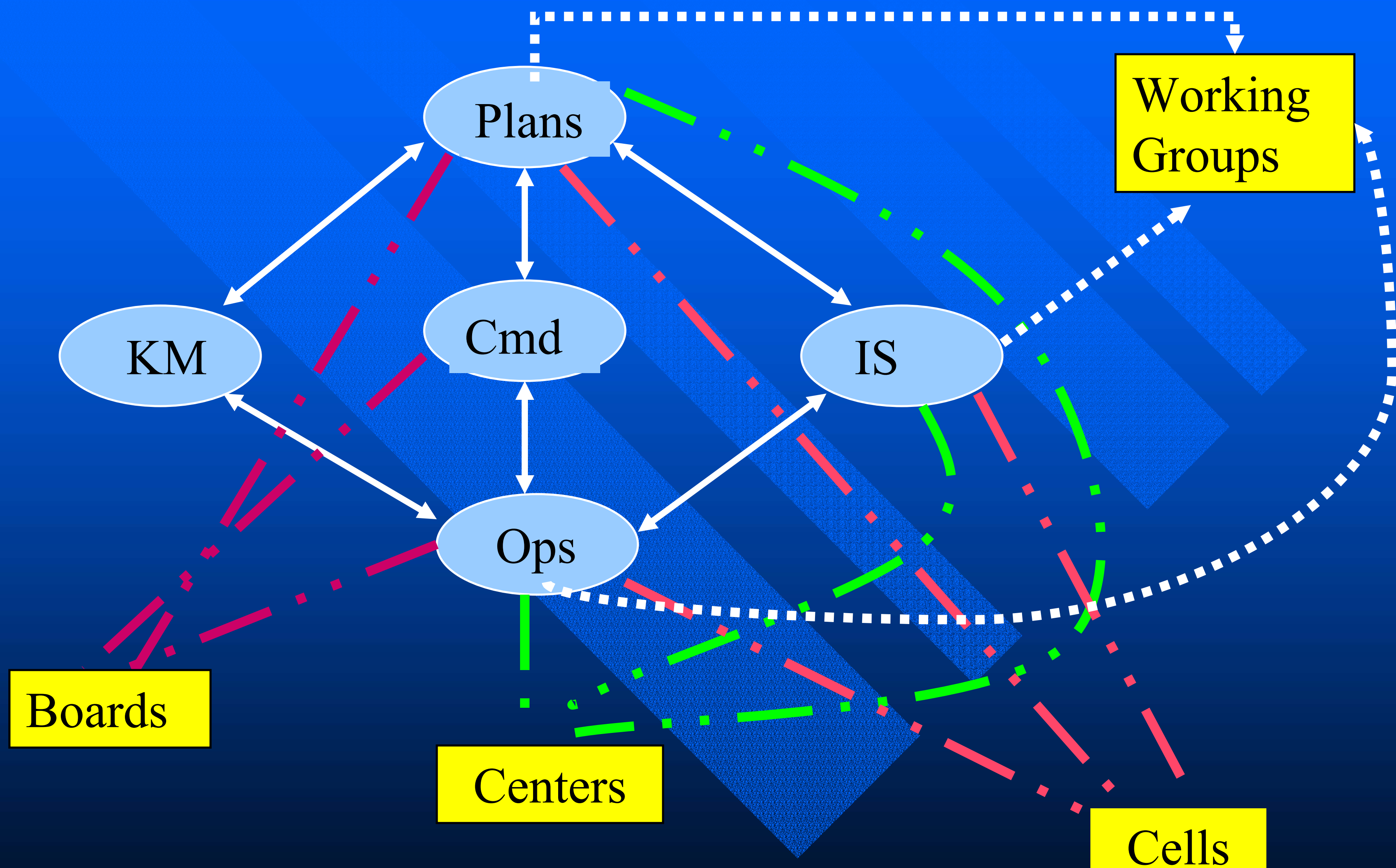


Decision	Enemy Who	Enemy What	Enemy Where	Enemy When	Friendly Who	Friendly What	Friendly Where	Friendly When	Friendly How
Time Since Update (min)	10	2	10	10	10	10	10	10	0
Frequency /Volatility Category	D	D	A	A	D	D	A	A	D
Decay Rate(% per min)	1	1	5	5	1	1	5	5	1
Info Quality (%)	90	98	50	50	90	90	50	50	100
Average Info Quality (%)	742								

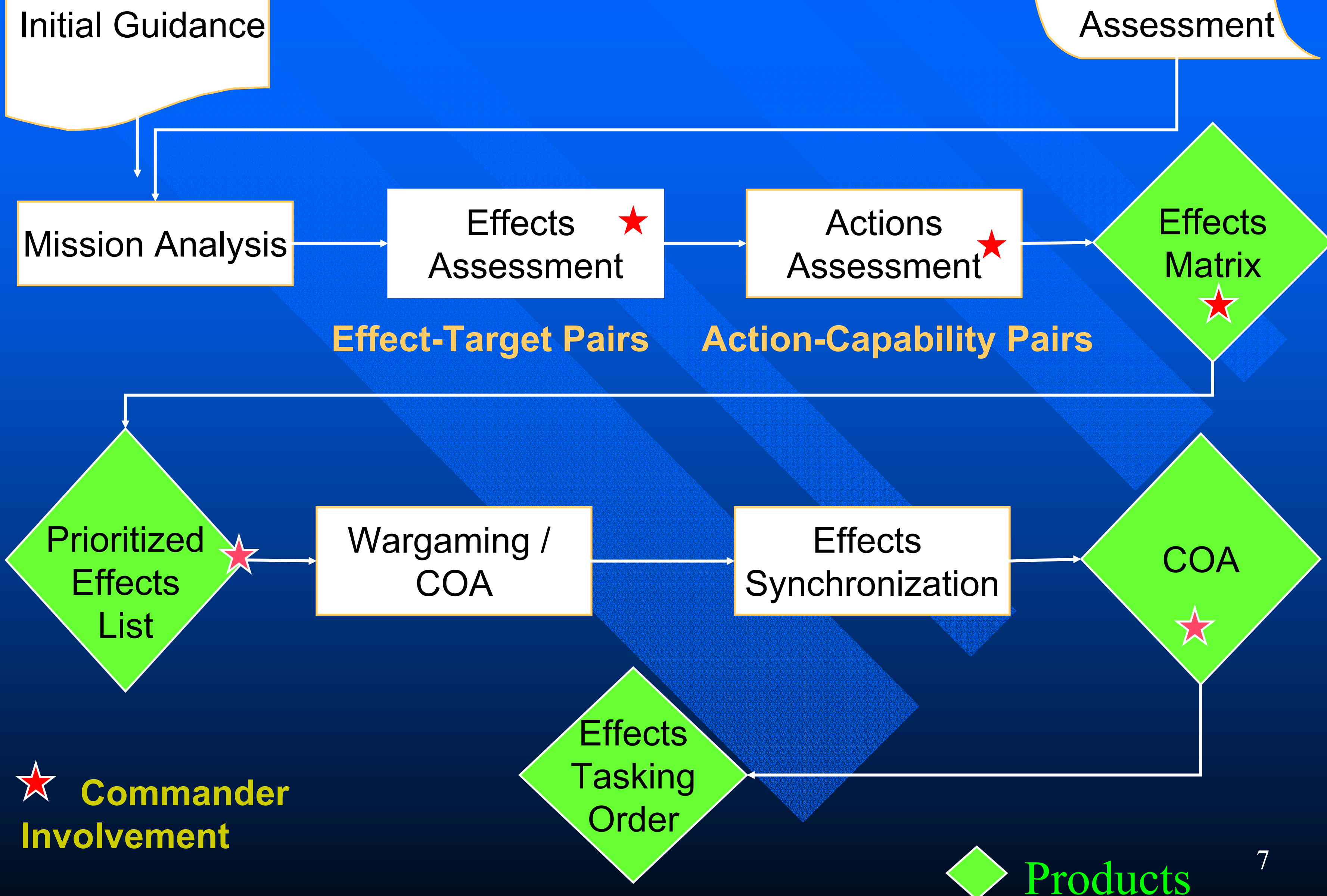
Questions we asked:

- Does the staff structure facilitate EBP?
- How are tasks distributed across staff groups?
- What communication events drive the process?
- Is the Commander adequately represented?

EBP Organization



EBP Process



Commander's Initial Guidance
Operational Net Assessment
Mission Analysis
Effects Assessment
Actions Assessment
Effects Matrix
Effect-Target Pairs
Action-Capability Pairs
Prioritized Effects List
Wargaming / COA
Effects Synchronization
COA
Effects Tasking Order
Commander Involvement
Products

Participants

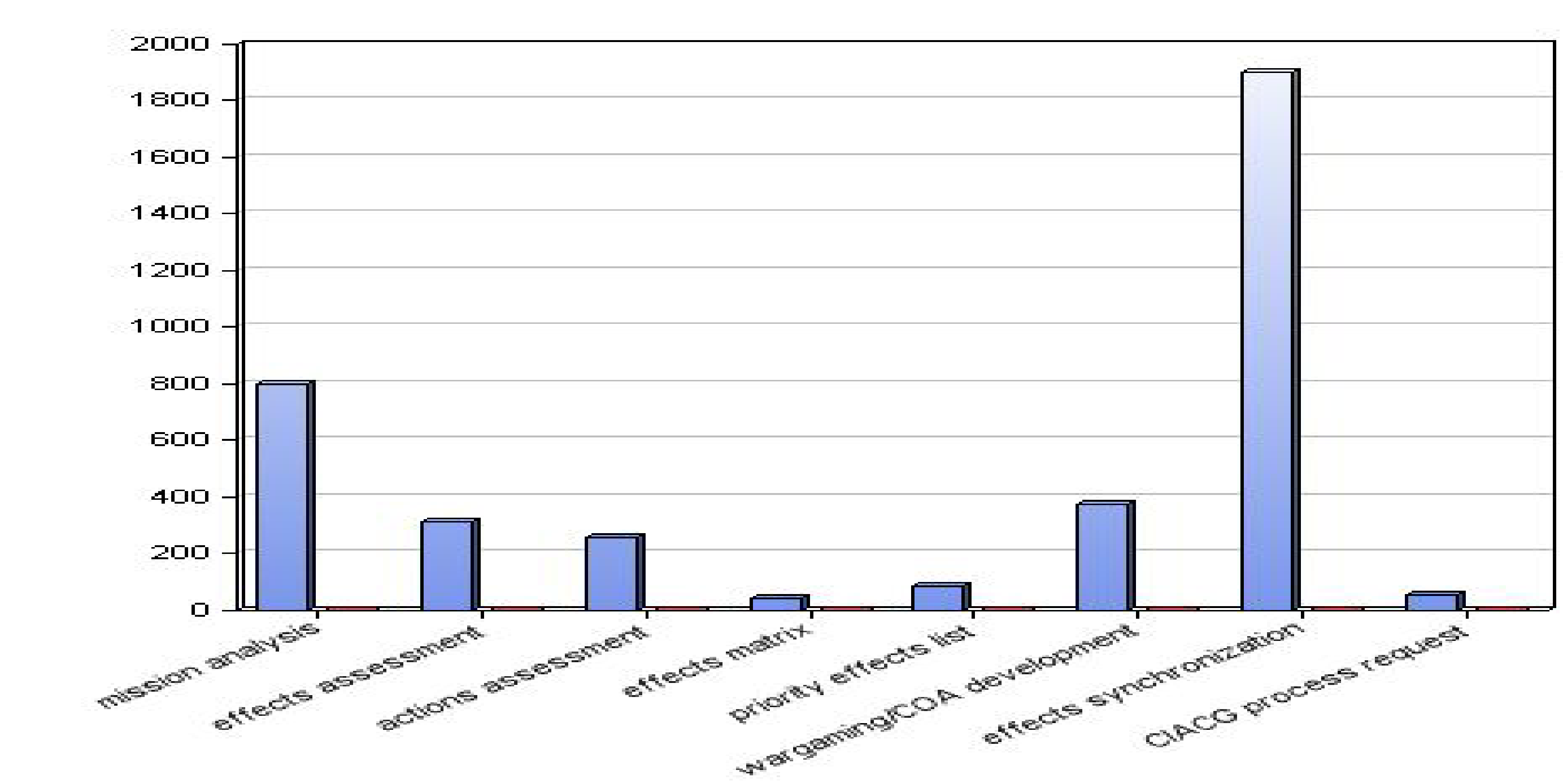
- CTF = 117, NRF = 34
- AU (6%), CA (12%), FR (13%), GE (18%), UK (18%), US (36%)
- Army (27%), AF (16%), Navy (18%), Marines (1%), Civilian (11%), Defense Contractor (24%), other (3%)
- Prior military experience = 90%
- No Experience with EBP = 77%
- No Experience in Dist Collab Envir. = 70%

Predicted Measures

- Task Times
- Staff Utilization
- Information Quality
- Situation Understanding

Task Times

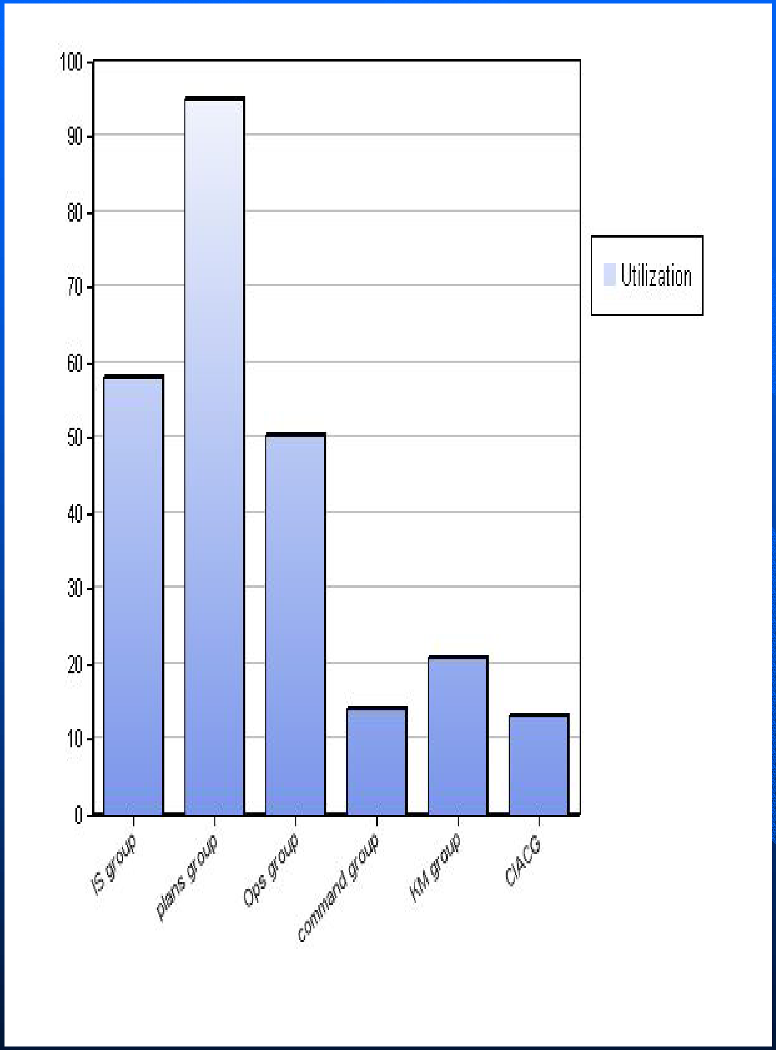
Mission Analysis and Effects Synchronization had highest task times due to collaboration requirements and difficulties



Collaborative Challenges

- Language (Terminology, acronyms, pace of conversation)
- Difficult to evaluate communications in a virtual environment.
- Confusion arising from doctrinal differences.
- Confusion over process.
- Confusion with organization

Staff Utilization



Plans (98%),

Ops (50%)

IS (58%),

KM (20%)

Cmd (14%),

CIACG (13%)

Overall judgment of information quality

Variable	Mean (7 point scale)	SD
Precision	3.45	1.49
Content	3.55	1.35
Sufficient	3.44	1.29
Accurate	3.57	1.32
Clarity	3.27	1.32
Timely	3.35	1.38
Current	3.56	1.30

Situation Understanding

- Ratings of SA and Information Flow were taken in each process step
- MANOVA between national groups showed no significant differences in the first three EBP stages
- In Effects Synchronization, significant differences were noted for 2 nations $\underline{F}(6, 73)=2.967$, $p=.012$
- 2 nations reported a significantly lower abililty to predict how events would develop in the Effects Synchronization stage.

Conclusions

- The Effects Synchronization stage was highly problematic, indicating the complex tasks involved
- The structure and functions in a cross-functional operational staff need refinement
- Modeling is a valuable tool to investigate the consequences of various structures and contributions of technologies
- New patterns of command involvement should be explored in a decentralized, virtual C2 structure to ensure appropriate levels of oversight